Modern Pollen Rain and Vegetational History of the Malaspina Glacier District, Alaska

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Seventy surface pollen samples from coastal forest, coastal meadow, muskeg, tree line, and alpine tundra communities form a basis for interpreting fossil pollen assemblages in the Malaspina Glacier district, Alaska. Pollen and macrofossil analyses of three radiocarbon-dated fossil sections from Icy Cape indicate that vegetational changes resulting from plant succession can be distinguished from those of migrational and climatic origin. Vegetation of the early Holocene xerothermic interval (10,000–7600 yr B.P.) was dominated by *Alnus* communities. Wetter conditions ensued, enabling generative muskeg surfaces to develop and first *Picea sitchensis*, then *Tsuga heterophylla* to expand from areas southeastward. Climatic cooling in more recent millennia (3500 yr B.P. to the present) is indicated by the appearance and persistent growth of *Tsuga mertensiana* and *Selaginella selaginoides* along this portion of the Gulf of Alaska coastline. © 1986 University of Washington.

INTRODUCTION

Deciphering plant succession from postglacial migration and from climatically induced vegetational change is of critical importance in paleoenvironmental reconstruction. The Malaspina Glacier district, a narrow corridor of land trending northwestward between lofty mountains and the sea, presents an unusual opportunity to address this phytogeographical challenge. Characterized by fluctuating glaciers, tectonic movement, and a cool maritime climate, this region has been considered a modern analog for paleoenvironments in the Puget Lowland of Washington during the late Wisconsin (Heusser, 1977; Thorson, 1980). Dense coniferous forests flourish on either side of Malaspina Glacier, the largest coastal piedmont glacier in North America. Interspersed in the forest are muskegs formed by centuries and millennia of peat accumulation. Three of these muskeg sections were selected to provide the basis for reconstruction of the Holocene vegetational history of Icy Cape.

An extensive palynological study of muskeg sections along the arcuate Gulf of Alaska coastline (Heusser, 1960) established a framework of vegetational history and climatic change for the entire Pacific Northwest. One section from Icy Cape in the Malaspina Glacier district traced the sequence of plant communities that occupied this region from 10,820 ± 420 yr B.P. to the present. Because the Gulf of Alaska coastline from Icy Cape to the Alsek River spans an area otherwise devoid of palynological investigation, this study of modern pollen–vegetation relationships and of pollen and macrofossil analyses of peat sections was undertaken to enlarge upon the district's Holocene environmental history.

REGIONAL ENVIRONMENTAL SETTING

Physiography and Glacial Geology

The study area extends about 220 km along the coast between 60°00N, 142°20′W and 59°10′N, 138°35′W (Fig. 1). It lies in the shadow of the highest coastal cordillera in the world, the St. Elias Mountains, with

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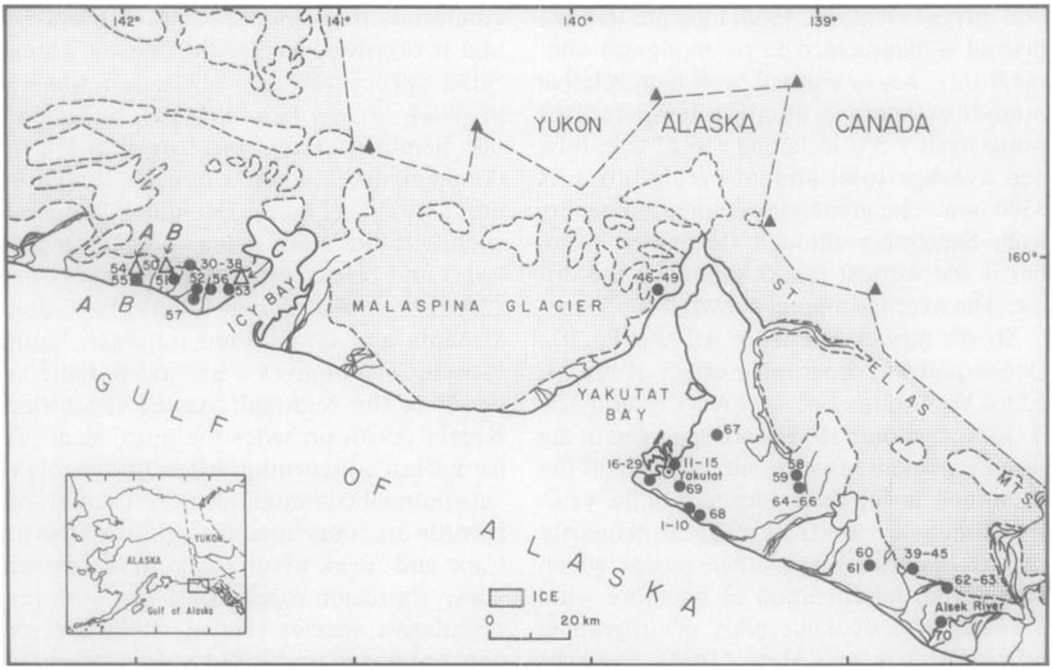


FIG. 1. Sketch map of Malaspina Glacier district showing the location of section sites by letter and modern pollen sites by number. Small triangles indicate peaks forming the U.S.–Canadian border.

elevations approaching 5500 m. The coastal fringe is dissected by rivers, bays, and glaciers; major features include Icy Bay, the enormous wasting piedmont lobe of Malaspina Glacier, Yakutat Bay, and Dry Bay. Depositional and erosional features resulting from glacial, tectonic, volcanic, and climatic events all attest to the setting's dynamic nature.

Extent of late Wisconsin ice in the Malaspina Glacier district is controversial. Surficial deposits indicate that the late Neoglacial ice limits are at least as extensive as those of the late Wisconsin (Plafker and Miller, 1958; Miller, 1958). Marine evidence, however, suggests a more extensive ice shelf 12,000 yr ago (Hamilton and Thorson, 1982; Molnia, 1983). Radiocarbon-dated debris from end moraines extending in some cases 22 km beyond the present ice front (Miller, 1958; Plafker, 1967; Plafker *et al.*, 1980) records ice advances in recent millennia. Major correlative glacial advances in the last few centuries are documented specifically from Glacier Bay (Goldthwait, 1966), from Lemon Creek Glacier near Juneau (Heusser and Marcus, 1964), and from the northeastern side of the St. Elias Mountains in Alaska and the Yukon (Denton and Stuiver, 1966; Denton and Karlén, 1973).

The general trend along this Alaskan Gulf coast in this century has been toward glacial stagnation and recession (Porter and Denton, 1967). Recent wastage of Malaspina Glacier is recorded (Sharp, 1956) and Guyot Glacier, which completely filled Icy Bay in 1904, has retreated over 40 km (Tarr and Martin, 1914). Notable exceptions to this recessional pattern are recent advances of Hubbard Glacier (Yehle, 1979) and several glaciers to the northwest in Prince William Sound.

Holocene global synthesis (Denton and Karlén, 1973) demonstrates two major Holocene advances (3300–2400 yr B.P. and the Little Ice Age of recent centuries) and five major recessions, as reflected by moraines in the northeastern St. Elias Mountains.

Climate

Climatic data from near sea level at Yakutat airport (Watson, 1968) indicate that the district is characterized by moderate temperatures, heavy rainfall, and high relative humidity. Average monthly temperatures range from −3°C in January to 12°C in July, and average total annual precipitation is 3300 mm. The greatest precipitation occurs from September through December. October is the wettest month and June the driest. The average annual snowfall is 550 cm.

Storm movement from off the Pacific Ocean and the orographic effect of the St. Elias Mountains are noteworthy climatic factors. Cyclonic storms are spawned in the semipermanent low-pressure system off the Aleutians during the cooler part of the year. Wind measurements at Yakutat primarily record easterlies or southeasterlies which result from modification of on-shore wind patterns by a cyclonic eddy of orographic origin (Bryson and Hare, 1974). Daylight hours range from 6 at midwinter to 19 at midsummer; the average growing season is 152 days (Kincer, 1941).

Vegetation

Regional vegetation consists primarily of coniferous trees interspersed with muskeg and is classified as Pacific Coastal Forest. Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and mountain hemlock (*Tsuga mertensiana*) are the dominant trees where drainage conditions are favorable (Fig. 2). Deciduous arboreals such as Sitka alder (*Alnus crispa* var. *sinuata*) and black cottonwood (*Populus balsamifera* subsp. *trichocarpa*) grow along streams and on flooded outwash lands. Heusser (1960) gives a general floristic account of the regional coastal vegetation. Knight (1976) provides the most recent information concerning different aspects of vegetational communities near Yakutat, but records are unfortunately lacking in the Icy Cape and Alsek River areas. In the present study six major vegetation types with representative species (Peteet, 1983) are recognized along an altitudinal gradient: (1) shoreline, (2) coastal meadow, (3) coniferous forest, (4) muskeg, (5) treeline, and (6) alpine tundra.

Youngest beach ridge forests consist primarily of Sitka spruce, an invader highly tolerant of salt spray (Daubenmire, 1968),

FIG. 2. Munday Creek, Icy Cape muskeg site showing gnarled *Tsuga mertensiana* in the foreground and coniferous forest, alder tree line, and alpine tundra in the background.

which ranges westward along the coast to Kodiak Island. As one moves inland into the older mixed coniferous forest, western hemlock appears in the mature spruce stands with better soils. The Alaskan western limit of western hemlock is the Kenai Peninsula (Hultén, 1968) and it is considered a climax species for the area (Cooper, 1937). Mountain hemlock occurs only occasionally in muskegs and forests of the Yakutat foreland but is more abundant at higher elevations west of Icy Bay, although still restricted to a small part of the forest canopy (R. McMahon, personal communication, 1980). It lives longest of the three conifers present, but never attains the diameter of Sitka spruce and western hemlock. Longevity is documented by an 800-yr tree-ring record from a mountain hemlock specimen growing upon a muskeg in Icy Cape (G. C. Jacoby and L. D. Ulan, personal communication, 1982). Westward, it is well represented as far as the Kenai Mountains.

METHODS

Field Study

Spruce, spruce–hemlock, hemlock, coastal meadow, muskeg, tree line, and alpine tundra communities were analyzed at elevations from near sea level to 655 m (Fig. 1, Table 1). The arboreal communities were sampled using the pointcentered quarter method (Cottam and Curtis, 1956) at 50 points along a 500-m linear transect and five moss surface samples were taken every 100 m along the transect for pollen analysis. Relative density, relative dominance, and relative frequency for each conifer species were calculated. Shrubs and herbs of all communities were analyzed using cover values within réléves (Braun-Blanquet, 1965). Quadrats measuring 4 × 4 m were employed for shrubs and 1 × 1 m for herbs. In coastal meadow, muskeg, tree line, and alpine tundra communities, random quadrats were analyzed and surface samples (moss polsters) collected from these quadrats. At each muskeg section site, five surface samples were collected for pollen analysis and quadrats sampled for cover values.

Three muskeg sites on an elevational and longitudinal transect inland from the coast (Fig. 1, Table 2) were selected on the basis of a visual assessment of aerial photographs, aerial reconnaissance, and preliminary probing to ascertain the depth of organic accumulation. Stratigraphic sections were taken using the Hiller coring device, which proved superior to the Livingstone corer in penetration of the fibrous peat. Sections were then subsampled for pollen analysis, macrofossil analysis, and radiocarbon dating.

Laboratory Study

Plant identification was aided by using keys given in Hultén (1968), Welsh (1974), and Viereck and Little (1974) and by reference to herbarium sheet specimens at the New York Botanical Garden. Plant nomenclature follows Hultén (1968).

Pollen and spores were concentrated from 1-cm^3 sediment subsamples. After initial KOH deflocculation, exotic *Eucalyptus* pollen grains were added to the samples to determine pollen concentration (Benninghoff, 1962). Subsequent processing included sodium pyrophosphate, HF, HCl, screening, acetolysis, and silicone oil mounts (Faegri and Iversen, 1975).

A minimum of 300 pollen grains were counted; the total pollen sum used for determination of relative frequency includes all species of pollen present. Cyperaceae, often excluded from pollen sums because of local overrepresentation, were included in this study for two reasons: (1) Cyperaceae are an important regional component of coastal and alpine tundra and possibly would appear as such in fossil assemblages. (2) A complete suite of pollen types in the sum is useful for comparisons of taxa represented in modern and fossil assemblages from sites elsewhere. Percentage of spores were based upon a sum of pollen and

TABLE 1. SITE DATA FOR SURFACE SAMPLES IN THE MALASPINA GLACIER DISTRICT, ALASKA

Sample No.	Location	Elevation (m)	Vegetation type
1–10	Cannon Beach Rd. near beach, Yakutat foreland	10	*Picea sitchensis* (100%) community
11–15	Ophir Creek area, Yakutat	20	*P. sitchensis* (85%)–*Tsuga heterophylla* (15%) community
16–29	Moraine north of Phipps Peninsula Rd., Yakutat	20	*T. heterophylla* (93%) community
30–38	West of Beare Glacier, Icy Cape	640	Alpine tundra
39–45	Rodman Peak, Yakutat	655	Alpine tundra
46–49	Bankas Point, western shore of Disenchantment Bay	104	Tree line
50,51	West of Davis Creek, Icy Cape	287	Muskeg
52	East of Big Sandy Creek, Icy Cape	229	Muskeg
53	East of Watson Creek, Icy Cape	165	Muskeg
54	West of Munday Creek, Icy Cape	88	Muskeg
55	West of Munday Creek, Icy Cape	70	Muskeg
56	East of Crystal Creek, Icy Cape	55	Muskeg
57	West of Big River, Icy Cape	37	Muskeg
58,59	Slate Mesa, east of Russell Fiord, Yakutat	373	Muskeg
60,61	West of Akwe River, Yakutat foreland	335	Muskeg
62,63	Tanis Mesa, Yakutat foreland	220	Muskeg
64–66	Pike Lakes, Yakutat foreland	30	Muskeg
67	West of Situk River, Yakutat	15	Muskeg
68	West of Tawah Creek, Yakutat	15	Coastal meadow
69	East of Yakutat airport, Yakutat	15	Coastal meadow
70	West bank of Alsek River, Yakutat foreland	15	Coastal meadow

spores. Pollen diagram zonation was done by visual inspection and zonal boundaries form peak zones.

Macrofossils were separated from their organic matrix by soaking 50 cm^3 of peat overnight in 5% potassium hydroxide, then washing with water through screens with 1.0-, 0.5-, and 0.25-mm meshes. The constituent seeds, twigs, fruits, needles, leaves, sterigmata, and macrospores were stored in a formalin–alcohol mixture and identified using modern reference material collected at the sites. Data are presented as the total number of macrofossils of each taxa per 50 cm^3 of sampled interval.

RESULTS AND DISCUSSION

Modern Pollen–Vegetation Relationships

The basis for interpretation of fossil pollen assemblages is the present-day relationship of vegetation to pollen rain. Many recent palynological studies have dealt with this relationship in order to precisely characterize the source vegetation of modern pollen analogs (Heusser, 1969; Birks, 1977; Hebda, 1983).

TABLE 2. SECTION DATA FOR MUSKEG SITES IN THE MALASPINA GLACIER DISTRICT, ALASKA

Site	Muskeg section	Location	Elevation (m)	Total depth (cm)	Lithology and depth (cm)	Dated intervals (cm)	^{14}C Age (yr B.P.)	Laboratory number
A	Munday Creek, Icy Cape	60°02'N 141°58'W (NW¼ NE¼ sec 11, T 22 S, R 20 E)	88	550	Bryophytic peat (0–265)	145–150	3500 ± 90	W5126
					Fibrous peat (265–400)	295–300	3860 ± 100	W5129
					Detritus peat (400–500)	455–460	7630 ± 60	W5131
					Woody peat (500–510)	505–510	7700 ± 110	W4825
					Detritus peat (510–540)	515–530	9000 ± 90	W4802
					Silty clay (540–550)			
B	Davis Creek, Icy Cape	60°02'N 141°52'W (SE¼ NW¼ sec 8, T 22 S, R 21 E)	287	180	Fibrous–bryophytic peat (0–160)	160–180	3410 ± 60	W4798
					Clayey peat (160–180)			
C	Watson Creek, Icy Cape	59°59'N 141°35'W (NE¼ SE¼ sec 24, T 22 S, R 22 E)	165	90	Fibrous–bryophytic peat (0–78)	80–90	840 ± 70	W4752
					Woody peat (78–80)			
					Fibrous–bryophytic peat (80–90)			

Seventy surface samples taken in this study (Figs. 3 and 4) from a variety of vegetation sites are very important aids in understanding (a) local pollen variation and its relation to modern vegetation, (b) the degree to which pollen variation reflects local pollen overrepresentation in the fossil muskeg sections, and (c) a means of interpreting the fossil pollen assemblages using modern analogs. Table 3 compares the relative pollen and spore frequency of selected taxa in surface samples to cover values for taxa from quadrats where the samples were obtained.

Each of the vegetational types is identifiable as a group by its characteristic pollen and spore assemblage (Figs. 3 and 4). Thus, *P. sitchensis* communities display pollen frequencies of spruce close to 75% which are not found in any other group. *T. heterophylla* is underrepresented, as shown by its low values in communities where it makes up 93% of the relative density and in the *P. sitchensis–T. heterophylla* communities where it displays minimal values and yet represents 15% of the forest density (Fig. 3). *Alnus crispa* var. *sinuata* pollen, as noted in other studies (Heusser, 1973, 1983), is greatly overrepresented.

Coastal meadow spectra require more study before a typical pollen assemblage can be described. However, these samples (Fig. 4) are dominated by Gramineae, Cyperaceae, *Myrica gale*, and *Salix*, which reflects community composition. Although all samples were within 50 m of *P. sitchensis* communities, *Picea* pollen values reach only 25%.

Determination of fossil pollen values at which a taxon is presumed to grow locally

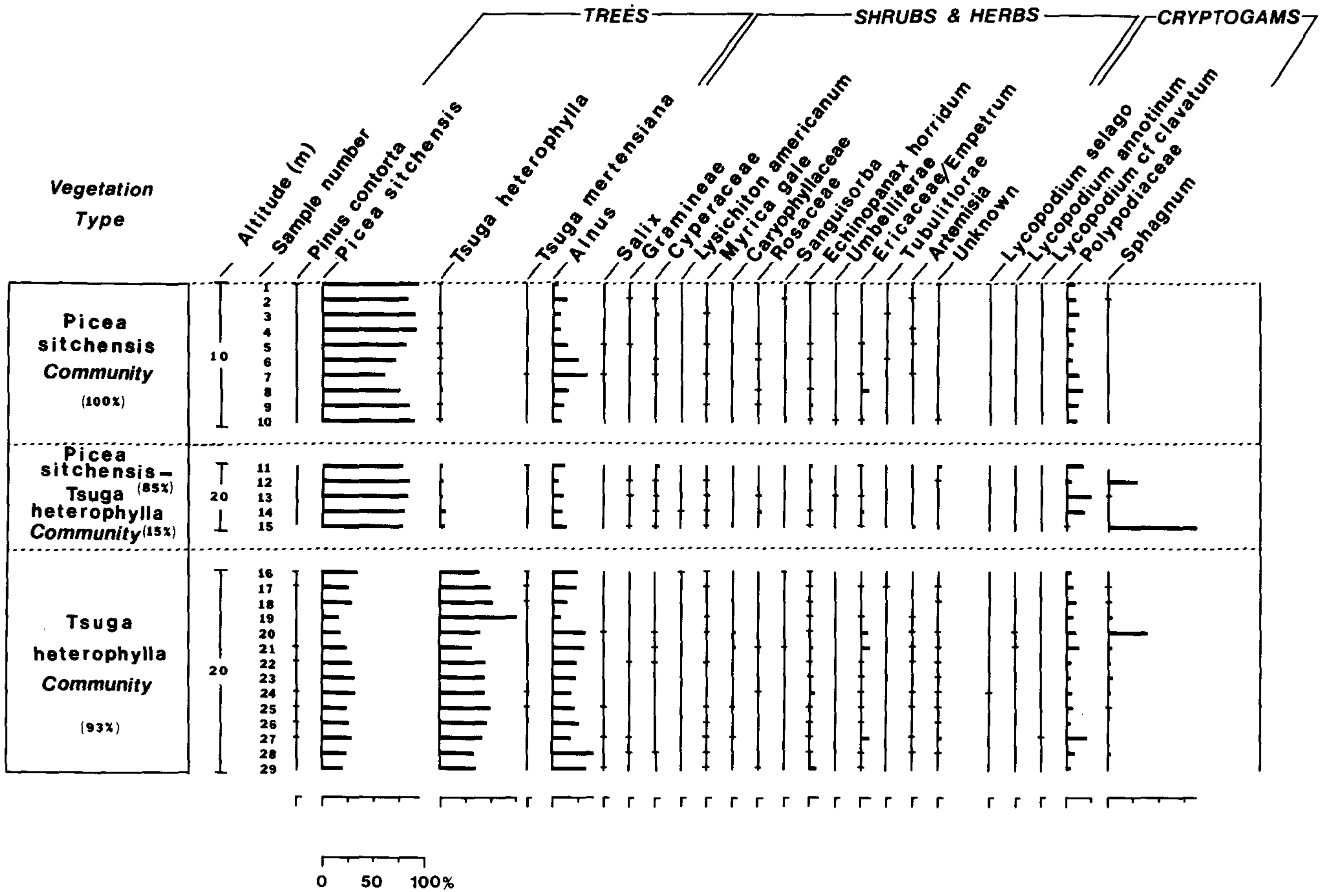


FIG. 3. Pollen and spore frequency diagram of surface spectra from coniferous communities at Yakutat. Numbered sites are located in Figure 1. Plus signs (+) represent values of less than 2%.

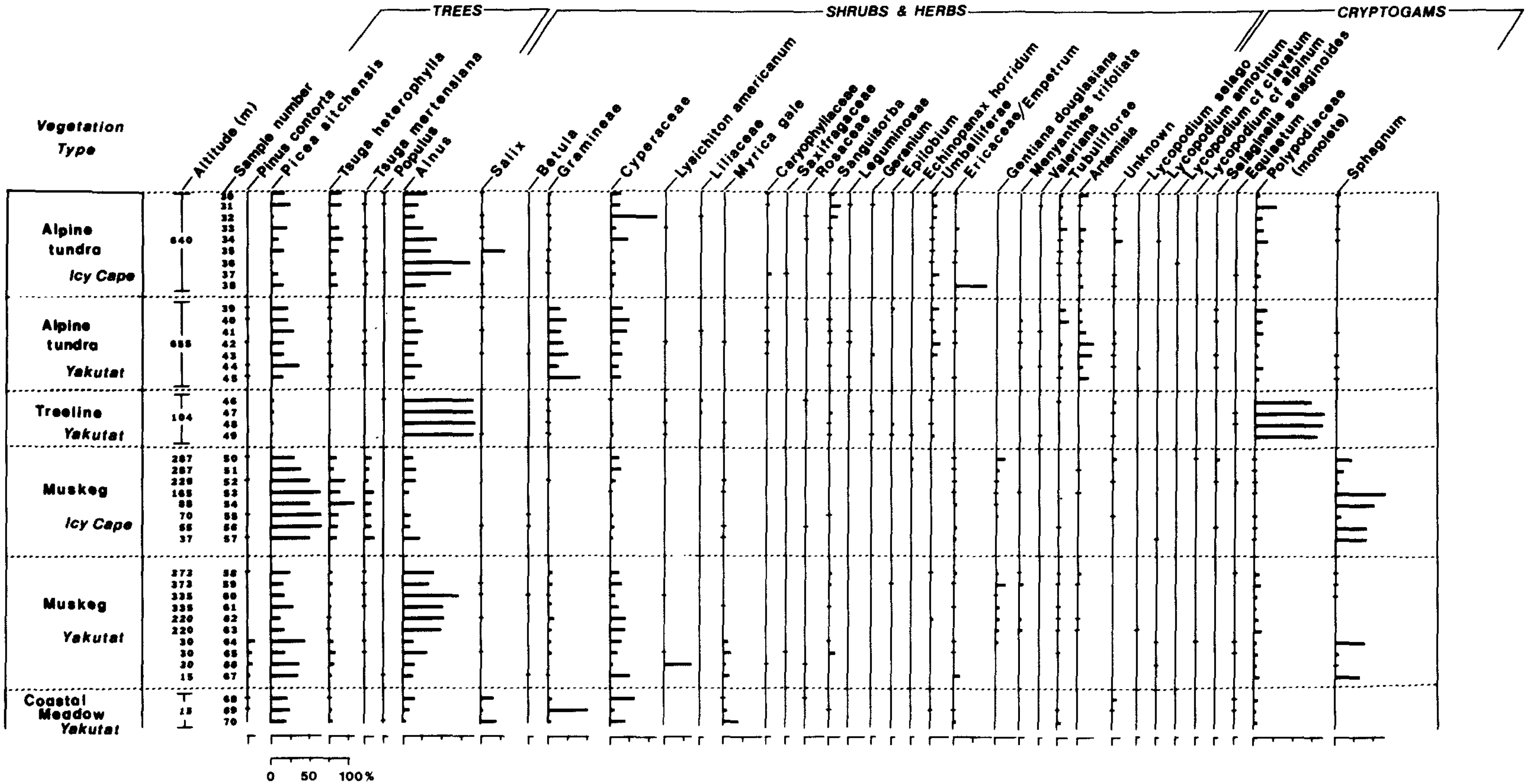


FIG. 4. Pollen and spore frequency diagram of surface spectra from meadow, muskeg, tree line, and alpine communities in the Malaspina Glacier district. Numbered sites are located in Figure 1. Plus signs (+) represent values of less than 2%.

TABLE 3. MODERN POLLEN–VEGETATION COMPARISONS FOR SELECTED TAXA

Vegetation type	Coastal meadow				Muskeg (Yakutat)										Muskeg (Icy Cape)							Tree line (Yakutat)				Alpine tundra (Yakutat)							Alpine tundra (Icy Cape)								
Sample No.	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30
Selected taxa																																									
PV																																									
CV																																									
Alnus	1	1	2	2	2	3	2	3	4	4	4	3	3	2	1	1	–	1	2	2	1	5	5	5	5	2	2	2	2	2	2	2	3	4	5	3	3	3	2	2	3
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	3	3	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Salix	2	1	2	–	–	+	–	–	+	–	+	+	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	+	–	+	–	+	+	–	1	3	+	+	+	–	+
	3	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	1	1	3	–	–	–	–	–
Gramineae	1	4	1	+	–	1	1	1	1	1	+	1	1	–	–	–	–	–	+	–	–	+	+	+	+	3	2	3	2	2	2	2	–	+	+	+	1	1	+	+	1
	+	3	1	–	–	3	5	3	3	3	3	2	2	–	–	–	–	3	–	2	2	–	–	–	–	3	3	3	3	3	3	3	–	4	1	–	3	2	3	2	3
Cyperaceae	2	1	3	3	1	1	2	2	2	2	1	2	2	1	1	1	–	+	1	2	2	1	1	+	+	2	1	2	2	2	2	2	1	1	1	1	2	1	4	2	2
	–	–	1	3	–	–	–	–	–	–	–	2	2	3	5	3	–	–	4	1	1	–	–	–	–	1	1	1	1	1	1	1	–	1	+	–	–	+	–	–	+
Myrica gale	2	1	+	1	1	2	1	–	–	+	–	–	–	+	+	–	–	+	+	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
	3	2	3	1	2	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Umbelliferae	–	+	–	–	–	–	–	+	1	+	–	1	+	–	–	–	–	–	–	–	–	1	+	–	+	1	–	1	2	1	+	1	+	1	+	+	+	+	1	1	1
	+	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–	–	–	–	1	1	1	1	–	–	–	–	–	–	–	–	3	–	–	–	–	1	1	+
Ericaceae/ *Empetrum*	1	+	–	2	–	+	+	–	–	+	–	+	1	1	1	–	1	+	+	+	+	–	–	–	–	+	–	+	+	+	+	1	3	–	+	+	+	1	–	–	+
	–	3	–	2	+	+	+	1	1	2	2	1	1	2	2	+	+	+	+	+	+	–	–	–	–	2	2	2	2	2	2	2	2	–	3	1	–	–	1	–	–
Gentiana douglasiana	–	–	–	–	–	–	+	1	1	1	+	2	1	–	–	2	+	+	+	2	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	2	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tubuliflorae	1	+	+	–	–	+	–	+	+	+	–	+	+	–	+	–	–	–	–	–	–	–	–	–	+	+	1	+	1	–	2	1	–	+	+			1		1	1
	1	+	1	–	+	+	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1		–	+
Artemisia	–	–	–	–	–	–	–	+	+	–	–	+	1	–	–	–	–	+	–	+	–	–	–	–	–	2	1	2	2	1	1	1	1	1	+	+	1	1	–	+	1
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Polypodiaceae	1	1	1	1	1	1	1	1	1	1	1	1	1	+	+	+	–	+	+	+	+	5	5	5	4	1	1	1	1	1	1	2	+	1	1	1			+	3	1
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	2	2	2	–	–	–	–	–	–	–	–	–		–	–	–	3	2	–

Note. Pollen and spore percentages (PV) are expressed as follows: + = <2%; 1 = 2–10%; 2 = >10–25%; 3 = >25–50%; 4 = >50–75%; 5 = >75–100%. Cover values (CV) follow the Braun-Blanquet system (Braun-Blanquet, 1965) in which + = few individuals, small cover; 1 = .5–5%; 2 = >5–25%; 3 = >25–50%; 4 = >50–75%; 5 = >75–100%.

is crucial in plant migration studies. Percentage spectra represent relative variation and are difficult to interpret. Pollen influx is a better indicator of species population expansion (Watts, 1973), but is not reliable when deposition rates are variable. Macrofossils, which are not widely dispersed, provide the best evidence of local presence. Macrofossil data along with relative pollen frequency are used to define the arrival dates of *P. sitchensis* and *T. heterophylla* at Icy Cape. In the absence of macrofossils, however, a critical pollen frequency value is postulated for local presence of arrival.

Because *P. sitchensis* pollen appears slightly overrepresented in surface samples (Figs. 3 and 4), fossil values above 5–10% would suggest its local arrival. In contrast, *T. heterophylla* is underrepresented in surface pollen samples, thus fossil percentages of 2% seem acceptable for its occurrence at a site. Surface values of less than 2% from muskegs where *T. mertensiana* is present suggest that minimal values of this species (less than 2%) may indicate its close proximity to the section site.

In attempting a reconstruction of paleoenvironments using surface moss samples and muskeg peat samples, it is especially important that *muskeg* surface pollen–vegetational relationships are understood. Jacobson and Bradshaw (1981) conclude in their analysis of site selection for paleovegetational studies that "peat deposits may contain the best pollen record for regional paleoclimatic or paleovegetational reconstructions." This conclusion is based on the contention that most pollen deposition is aerial and that local pollen can be separated from regional. The muskeg pollen profiles in this surface pollen study suggest that a regional picture is reflected in the fossil record and that the local plants do not contribute substantially to the pollen record, with the exceptions of Cyperaceae, *Myrica gale*, and *Lysichiton*.

A clear contrast in the conifer community composition between Icy Cape and Yakutat is reflected in the muskeg surface pollen spectra (Fig. 4), as *P. sitchensis*, *T. heterophylla*, and *T. mertensiana* are better represented throughout the Icy Cape muskeg samples. *Pinus contorta*, in contrast, reaches values greater than 2% only where it grows today in the Pike Lakes area near Yakutat.

Because *Gentiana douglasiana* pollen appears only in muskeg samples, it can be inferred that its dispersal is local and indicative of a muskeg environment. High percentage of *Lysichiton* in one sample (66), where the plant was absent in the local vegetation suggests that the pollen was a product of the previous year's growth. If the pollen was wind dispersed, it would presumably appear in more samples. Polypodiaceae spores, in contrast, are interpreted as being produced in great quantities and windblown, because of their ubiquitous presence; however, the muskegs at Icy Cape do not show the frequencies characteristic of those near Yakutat. This possibly reflects the terrain surrounding the Yakutat muskegs, which is more exposed, open, and colonized by plant pioneers (*Alnus*, Polypodiaceae) while the Icy Cape muskegs lie in more protected locations, surrounded by forest communities.

Modern tree line pollen and spore percentages are especially significant because they provide an *Alnus*–Polypodiaceae analog not visible in any other vegetation type (Fig. 4). This analog compares favorably with the basal pollen assemblage zone represented in most of the sections. *P. sitchensis*, close to the sites, figures only negligibly in these surface pollen samples.

Throughout modern surface spectra from alpine tundra (Fig. 4), Umbelliferae, Tubuliflorae, and *Artemisia* along with Gramineae and Cyperaceae form a distinctive assemblage despite the fact that conifers are also present. Where pollen percentages of *Picea* and *T. heterophylla* are comparable in the Icy Cape tundra samples it can be inferred, based on modern pollen–modern vegetation study, that *T. heterophylla* grows closer to the site than *P.*

sitchensis or is better represented in the nearby forest community. Significant percentages of the Polypodiaceae at all locations in the alpine zone indicate that the spores are windblown, probably from tree line.

Pollen Stratigraphy of Icy Cape

Six pollen assemblage zones are recognized at Munday Creek (Fig. 5): M-6, *Alnus*–Polypodiaceae; M-5, *Alnus–Lysichiton;* M-4, *P. sitchensis*–Cyperaceae; M-3, *P. sitchensis–T. heterophylla*–Cyperaceae; M-2, *P. sitchensis–T. heterophylla–T. mertensiana;* and M-1, *P. sitchensis–T. heterophylla–T. mertensiana–Alnus*. Zone M-6, *Alnus*–Polypodiaceae, is below the radiocarbon-dated interval of 9000 ± 90 yr. *Alnus* and the Polypodiaceae are best represented in zone M-6; *P. sitchensis* and *T. heterophylla* also occur with frequencies over 2% in the silty clay, only to subsequently drop as *Salix* reaches its maximum percentages (5%). Zone M-5 features highest values for *Alnus* (up to 96%) along with a steady increase of up to 55% in *Lysichiton*. During this interval, conifer pollen disappears, Cyperaceae values are less than 2%, and Polypodiaceae spores gradually decline. Zone M-4 is characterized by a steady rise in *P. sitchensis* (up to 40%) concomitant with a decrease in *Alnus*. Cyperaceae values increase within this zone to maximum values of 74%. *Lysichiton* drops drastically to less than 2% and Polypodiaceae to negligible values, while *Gentiana douglasiana* and Umbelliferae are best represented.

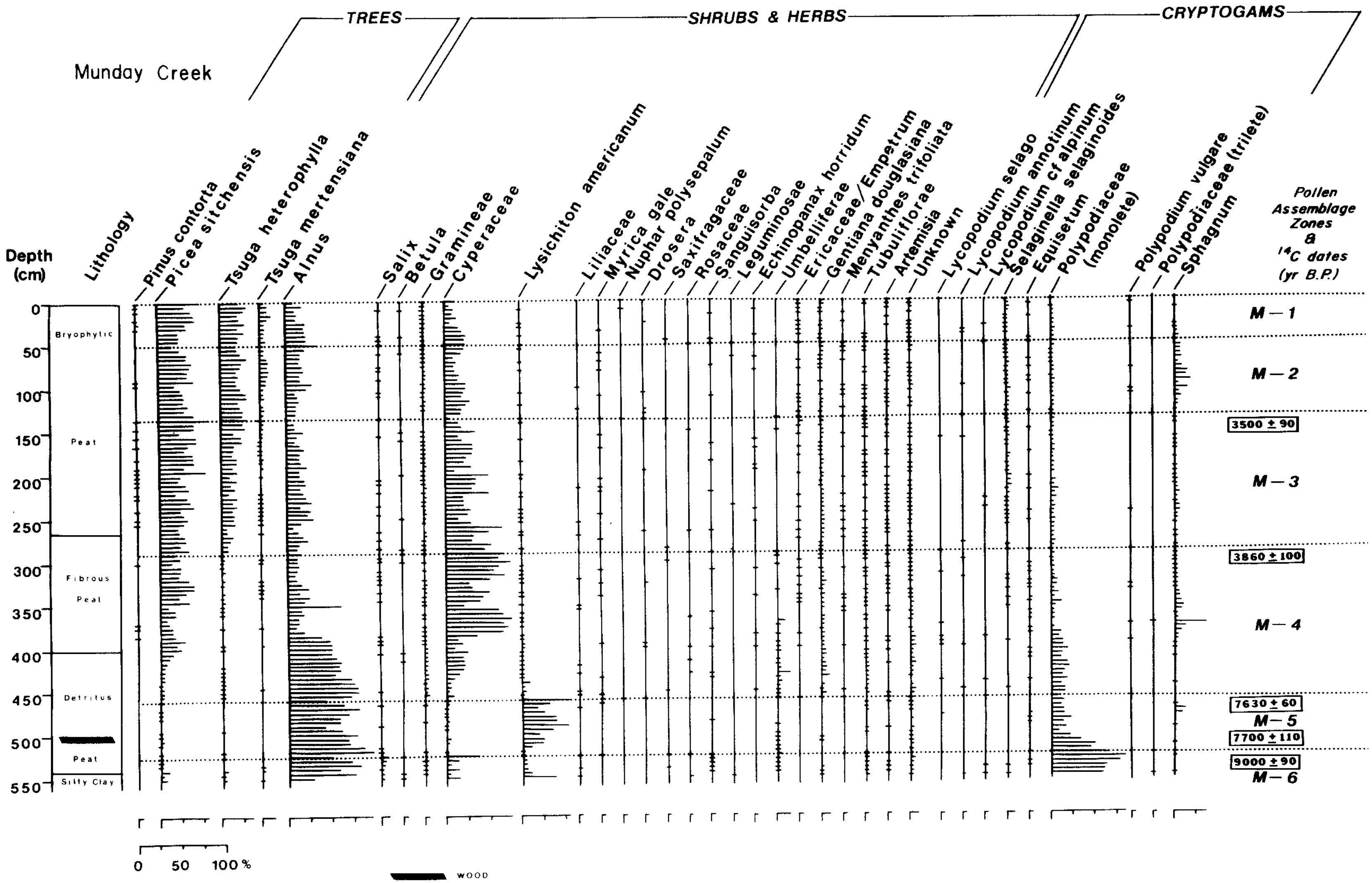
The rise in *T. heterophylla* and *P. sitchensis* along with a decrease in Cyperaceae defines zone M-3; *Selaginella selaginoides* reaches maximum values within this zone. Zone M-2 records the rise of *T. mertensiana*, and *P. sitchensis* and *T. heterophylla* remain greater than or equal to 25%; *Sphagnum* spores are consistently high within this zone. In zone M-1, the increase of *P. sitchensis* along with a decrease in Cyperaceae are the apparent changes while *T. heterophylla* and *T. mertensiana* values remain relatively high.

Vegetational History of Icy Cape

The earliest vegetational record (10,820 ± 420 yr B.P.) in the Malaspina Glacier district is represented by the data at the base of Heusser's (1960) Icy Cape section. Pollen profiles from his section are strikingly similar to those of this study (Fig. 5), suggesting that local vegetative variations from adjacent muskegs do not necessarily mask regional vegetation signals. Pioneer coastal tundra communities consisting of Cyperaceae and Ericaceae/*Empetrum* (Heusser, 1960) were followed by the expansion of *Alnus* and Polypodiaceae populations as climate ameliorated. By 9000 yr ago, *Salix* and *Lysichiton* probably grew near the site. As *Alnus* expanded and nitrogen was added to the mineral soils, *Rubus spectabilis, Rubus* cf. *parviflorus,* and *Sambucus racemosa* (Fig. 6) were also able to compete successfully for resources.

The ensuing *Alnus–Lysichiton* interval (approximately 7700–7600 yr B.P.) occurs in Heusser's (1960) section as well. Today, *Lysichiton* thrives in shaded forest communities where drainage is impeded and paludification apparent. The peat, pollen, and seed stratigraphy (Figs. 5 and 6) during this interval suggest that *Alnus* forest communities occupied the Icy Cape region. Similar correlated woody recurrence surfaces occurring in the peat sections throughout southeastern Alaska and coastal British Columbia are attributed to drier climatic conditions (Heusser, 1960, 1966). Thus, although *Alnus* expanded regionally and muskeg growth was limited, fossil deposition locally took place in a wet environment and preservation is good. Evidence for a relatively warm, drier interval

FIG. 5. Pollen and spore frequency diagram from section A at Munday Creek. Plus signs (+) represent values of less than 2%.


Munday Creek
TREES
SHRUBS & HERBS
CRYPTOGAMS
Depth (cm)
Lithology
Pinus contorta
Picea sitchensis
Tsuga heterophylla
Tsuga mertensiana
Alnus
Salix
Betula
Gramineae
Cyperaceae
Lysichiton americanum
Liliaceae
Myrica gale
Nuphar polysepalum
Drosera
Saxifragaceae
Rosaceae
Sanguisorba
Leguminosae
Echinopanax horridum
Umbelliferae
Ericaceae/Empetrum
Gentiana douglasiana
Menyanthes trifoliata
Tubuliflorae
Artemisia
Unknown
Lycopodium selago
Lycopodium annotinum
Lycopodium cf alpinum
Selaginella selaginoides
Equisetum
Polypodiaceae (monolete)
Polypodium vulgare
Polypodiaceae (trilete)
Sphagnum
Pollen Assemblage Zones & ¹⁴C dates (yr B.P.)
Bryophytic
Peat
Fibrous Peat
Detritus
Peat
Silty Clay
0
50
100
150
200
250
300
350
400
450
500
550
M — 1
M — 2
3500 ± 90
M — 3
3860 ± 100
M — 4
7630 ± 60
M — 5
7700 ± 110
9000 ± 90
M — 6
0 50 100 %
WOOD

during the early Holocene along the south-central Alaskan coast appears to agree with records to the southeast in coastal Alaska (Heusser, 1960, 1966) and British Columbia (Mathewes and Heusser, 1981). Hebda (1983) cites distinctive evidence for a xerothermic interval between 8800 and 7000 yr B.P. on Vancouver Island, B.C., and provides a regional synthesis of Pacific Northwest data which supports this view.

Approximately 7600 yr ago, the fossil record (Figs. 5 and 6) displays a decline in *Alnus* and *Lysichiton* concomitant with an increase in *Picea* pollen percentages and the presence of *P. sitchensis* sterigmata. The sterigmata, remnants of spruce twigs, establish firm evidence for the actual presence of *P. sitchensis* at Icy Cape. *P. sitchensis* communities colonized the region, and *Alnus crispa* var. *sinuata,* outcompeted in the typical successional sequence, colonized younger soils away from the muskeg site. Increase in *Gentiana douglasiana,* which is restricted to muskegs, suggests that the surface resembled the vegetational site at Munday Creek today. Sedge formed the dominant plant cover, as evidenced by the high Cyperaceae pollen values and sedge achenes; maximum numbers of achenes are recorded around 5500 yr B.P. Increasing dominance of this family, also apparent in Heusser's (1960) section, suggests that increases in precipitation enabled generative muskeg surfaces to develop regionally, covering the *Alnus* detritus.

The ensuing 150 cm of rapid peat deposition between approximately 3900 and 3500 yr B.P. strongly implies further increases in atmospheric moisture. The expansion of *T. heterophylla,* dated at 3860 yr B.P., also suggests an increase in available moisture as well as improved soil conditions. As *T. heterophylla* is underrepresented in the pollen rain, percentages found in this time interval indicate that this conifer had become an important component of the forest community. The presence of *T. heterophylla* seeds and needles verify its proximity to the muskeg, though *Picea* was still closer or more dominant.

Selaginella selaginoides growth during the centuries of *T. heterophylla* expansion is demonstrated in both microspore and macrospore records. Although optimal spore production requirements are unknown, *S. selaginoides* is found today on moist sites from British Columbia northwestward along the coast (Hultén, 1968). Its presence in Heusser's (1960) fossil sections from British Columbia northwestward is essentially restricted to the late postglacial, paralleling the expansion of *T. heterophylla* and *T. mertensiana*. Thus, climatic conditions at Icy Cape during these centuries of rapid peat deposition, *T. heterophylla* expansion, and *S. selaginoides* dominance were presumably wetter than in preceding millennia.

Stratigraphic studies of raised bog peat in the British Isles led Barber (1981) to conclude that changes in peat growth are directly related to climatic change. In an intensive investigation of muskegs throughout southeasten Alaska, Neiland (1971) found that peat sections frequently revealed bryophytic peat overlying fibrous peat. This parallels the general lithologic scheme in the present study. Neiland (1971) discusses the cycles of humification and nonhumification undergone by muskegs when conditions become more mesic. Drier, highly decayed peat may form even during brief droughts, forming impervious humified layers which lead to higher muskeg water tables when wetter conditions resume. As more water is held higher in the muskeg, nonhumified peat rapidly accumulates. Correlative fluctuation of recurrence surfaces with fibrous and bryophytic peat throughtout the eastern coastal region of the Gulf of Alaska (Heusser, 1960, 1966; Neiland, 1971) demonstrates climatic change throughout the Holocene.

Arrival of *T. mertensiana* at Icy Cape is dated about 3500 yr B.P. (Fig. 5). Although no macrofossils of this species were found, pollen percentages of greater than 2% suggest its presence because modern pollen percentages of *T. mertensiana* are sometimes less than 2%. Surface samples from

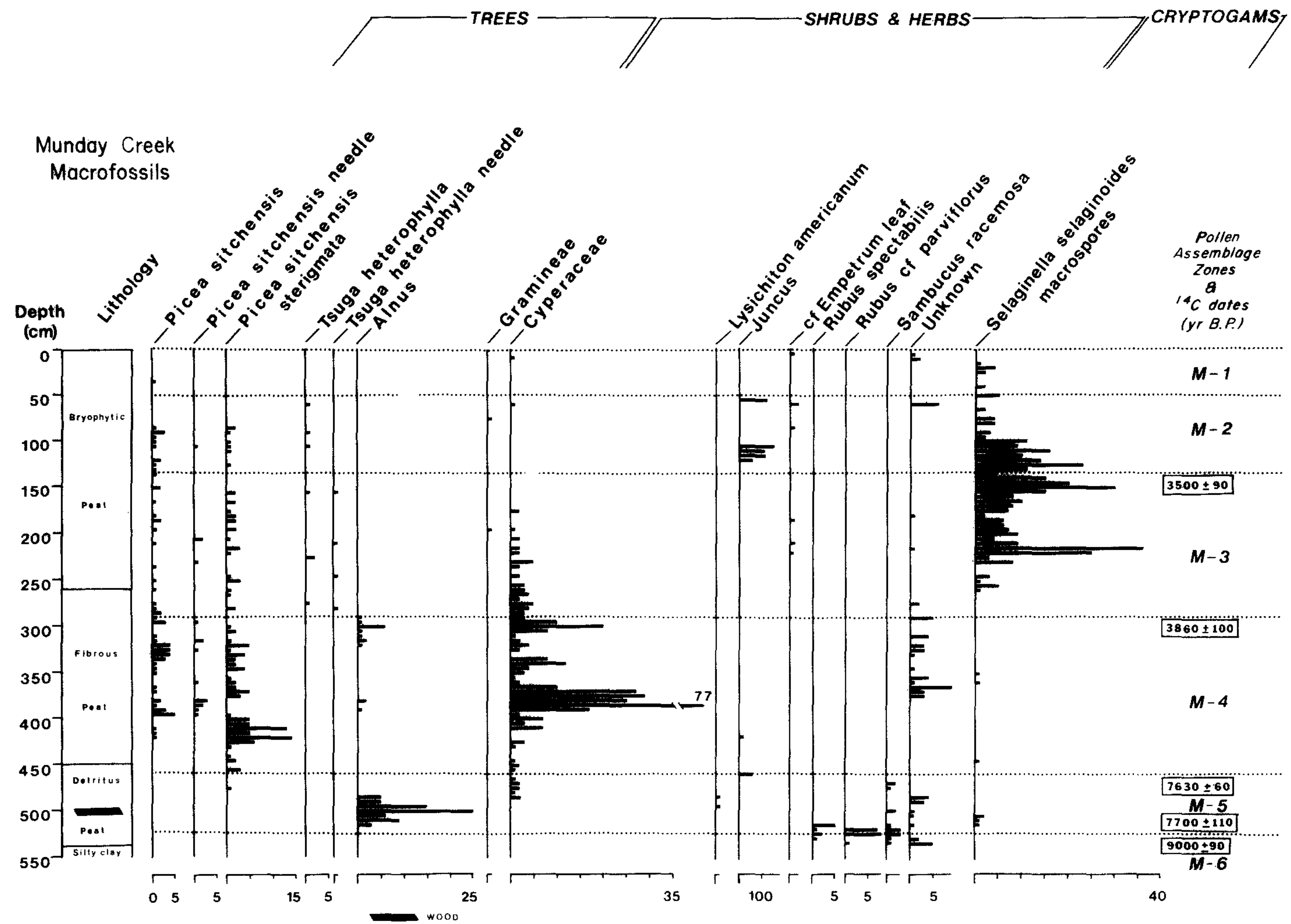


Fig. 6. Macrofossil diagram from section A at Munday Creek. Unless specified otherwise, macrofossils represent seeds.

Prince William Sound (Heusser, 1983), where *T. mertensiana* is a forest dominant, indicate that this interpretation of underrepresentation is valid. The implied forest community at Icy Cape consisted of *T. heterophylla* and *P. sitchensis* with *T. mertensiana* appearing in more montane settings and on muskegs, the habitats it favors today. Arrival of mountain hemlock in the Icy Cape region is further substantiated by its appearance in the Davis Creek section, slightly eastward, around 3400 yr B.P. (Fig. 7). This section exhibits a successional pattern of *Alnus*–Polypodiaceae colonization at the site. (However, based upon similar assemblages at Munday Creek and in modern pollen samples, other plant pioneers were probably present). Immediately thereafter, the fossil pollen record implies a *T. heterophylla–P. sitchensis–T. mertensiana* forest, with subsequent increases in sedge and sphagnum growth upon the muskeg.

Conditions that were conducive to the spread of *T. mertensiana* also caused glaciers to advance. Presence of *T. mertensiana* and increased *Sphagnum* growth in these two sections and others along this coast (Heusser, 1960, 1983) reflect Neoglacial cooling and increases in atmospheric humidity (Porter and Denton, 1967). Maximum advance of the Guyot Glacier, filling Icy Bay at 1400 ± 200 yr B.P. (Plafker *et al.*, 1980) occurred during Neoglaciation.

The Watson Creek site (Fig. 7), located between the two Neoglacial moraines of the Guyot Glacier, was probably ice covered until initiation of organic deposition about 840 yr B.P. Proximity of forest communities to the site, indicated by the presence of a *P. sitchensis* ligneous layer (Fig. 7), resulted in an initial pollen assemblage including conifers, *Alnus*, Polypodiaceae, and Rosaceae (probably including *Rubus* spp.). The record of *T. heterophylla, T. mertensiana, S. selaginoides*, and *Sphagnum* growth up to the present is indicative of the same general environmental regime characteristic of Icy Cape today.

Regional Correlation

Vegetational history of the Malaspina Glacier district is best understood considering the region's coastal geographic position between Prince William Sound and Lituya Bay. Although plant migration is sporadic, pollen zone correlation (Fig. 8) of the three fossil sites in this study with the palynological and chronological investigations to the northwest (Sirkin and Tuthill, 1969; Sirkin, 1983; Heusser, 1983), with nearby Yakutat (Peteet, 1983), and with areas southeast (Mann, 1983), provides a basis for the Holocene history of conifer migration northwestward and its climatic implications (Fig. 9).

Northwestward along the coast, in the Copper River and Katalla areas (Sirkin and Tuthill, 1969; Sirkin, 1983), deglaciation occurred much earlier than in the Malaspina Glacier district. Approximately 14,000 yr B.P., pioneer communities consisted of shrubs and herbs. In the Copper River basin, *Alnus* succeeded shrub–herb tundra around 11,000 yr B.P. and was dominant throughout the Holocene until the Neoglacial interval when *Picea* expanded (Sirkin, 1983). At Katalla, *Alnus* was present even earlier. It fluctuated with herbs until 9000 yr B.P. and then became dominant, paralleling *Alnus* dominance in the Copper River sections (Sirkin and Tuthill, 1969).

In Prince William Sound, deglaciation occurred prior to 10,000 yr B.P. (Heusser, 1983). Coastal sedge tundra, including thickets of *Salix* and *Alnus*, colonized the region. Later, *Alnus* expanded along with Polypodiaceae and was dominant until recent millennia when *T. mertensiana, P. sitchensis*, and *T. heterophylla* expanded at the time of Neoglacial cooling.

Southeastward from the Malaspina Glacier district, in the Alexander Archipelago (Heusser, 1952), and as far as the Queen Charlotte Islands (Heusser, 1960; Mathewes and Clague, 1982), *Pinus contorta* dominated the late-glacial and early postglacial intervals. At Lituya Bay it appears prior to the expansion of *Picea* at 8830 ±

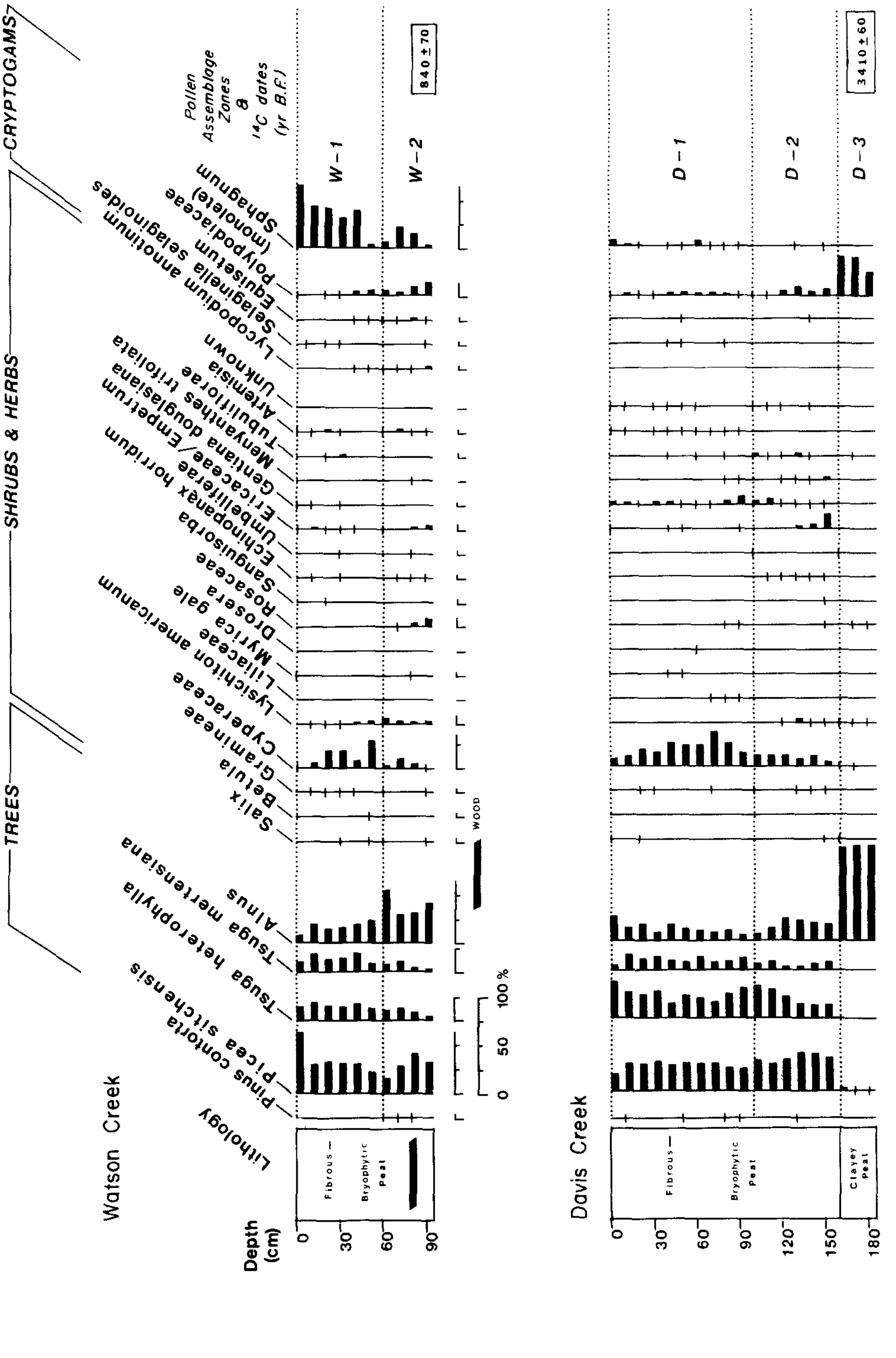


FIG. 7. Pollen and spore frequency diagram from sections B at Davis Creek and C at Watson Creek. Plus signs (+) represent values of less than 2%.

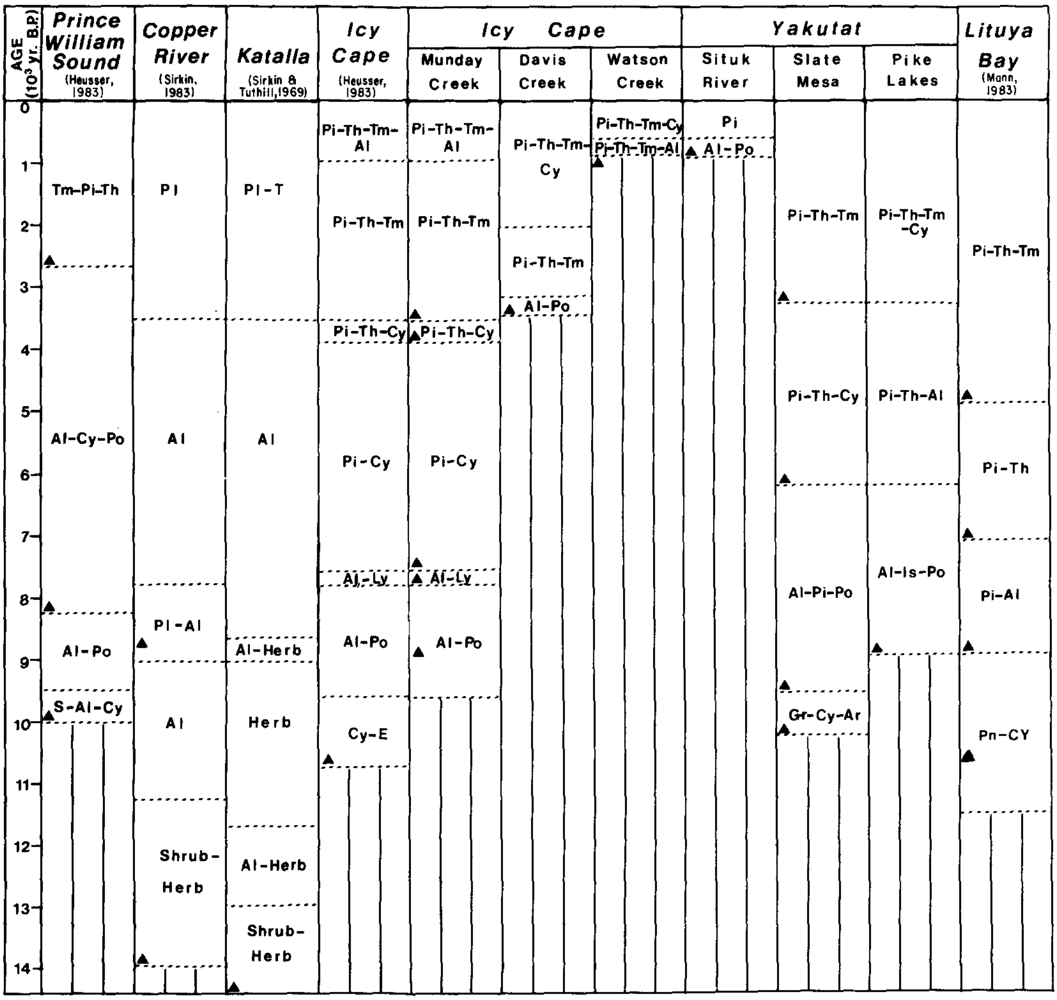


FIG. 8. Provisional correlation of pollen assemblage zones from investigations in south-central and southeastern Alaska. Triangles indicate radiocarbon-dated levels. Al-*Alnus*, Ar-*Artemisia*, Cy-Cyperaceae, E-Ericaceae/*Empetrum*, Gr-Gramineae, Is-*Isoetes*, Ly-*Lysichiton*, Pi-*P. sitchensis*, Pl-*Picea* sp., Pn-*Pinus contorta*, Po-Polypodiaceae, S-*Salix* sp., T-*Tsuga* sp., Th-*T. heterophylla*, Tm-*T. mertensiana*.

100 yr B.P. (Mann, 1983). *T. heterophylla* percentages increase in the pollen profile at Lituya Bay approximately 7140 yr B.P., and *T. mertensiana* populations expand at 4860 ± 80 yr B.P. (Mann, 1983). In the Queen Charlotte Islands (Heusser, 1966), late Holocene appearance of *T. mertensiana* pollen in the fossil record represents its first expansion since the late-glacial interval.

Centuries of alpine tundra conditions followed by *Alnus* dominance (10,220–9560 yr B.P.) at Yakutat (Peteet, 1983) before the arrival of *P. sitchensis* suggest that *Picea* may have been restricted southeastward by climatic conditions. Expansion of *P. sitchensis* populations at Lituya Bay (approximately 9000 yr B.P.) and Yakutat (sometime after 9560 yr B.P.) was apparently quite rapid, and indicates that *Picea* may have colonized Yakutat first. The subsequent 2000-yr lag between the appearance of *P. sitchensis* at Yakutat and Icy Cape (9560–7600 yr B.P.), a distance comparable to that between Lituya Bay and Yakutat, may be explained by fortuitous seed dispersal or by the obstacle represented by the Malaspina glacier or possible coastal embayment where it exists today. Farr and Harris (1979) cite the necessity of abundant moisture and lack of a prolonged drought for develop-

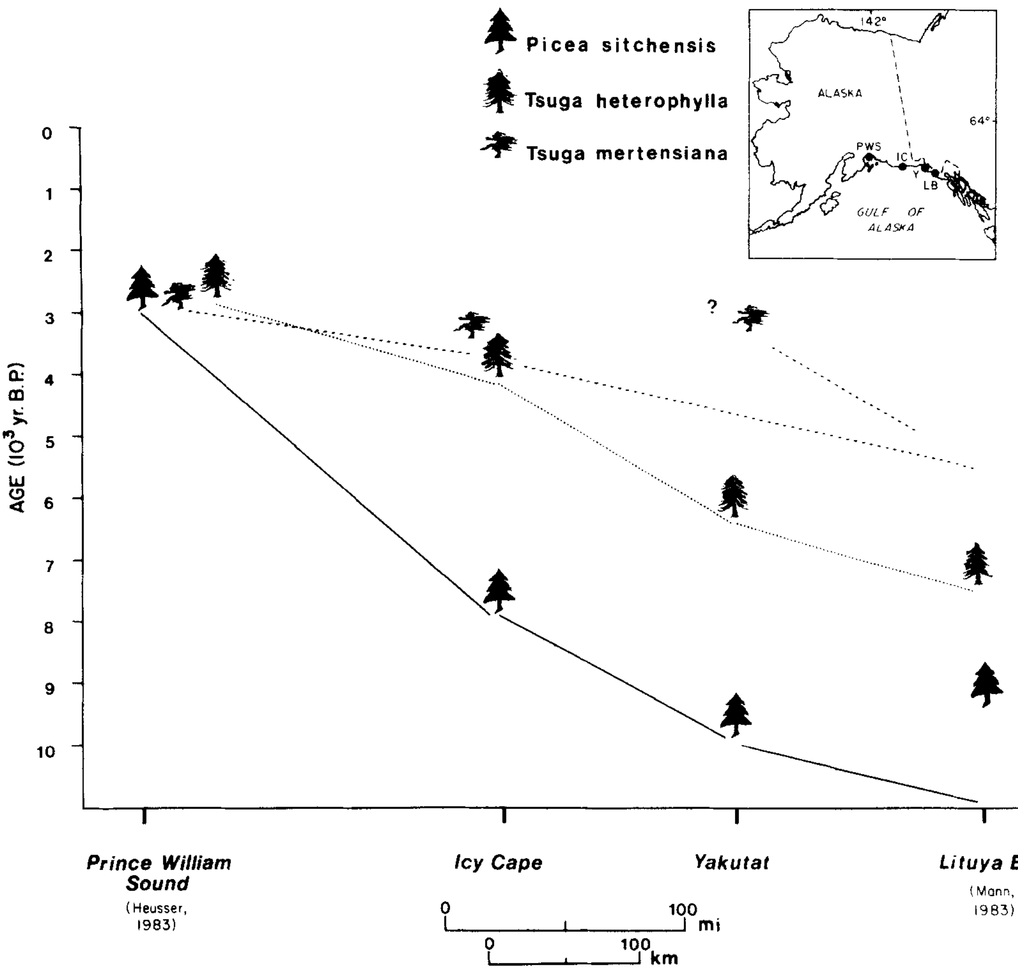


FIG. 9. Apparent Holocene conifer migration northwestward based on first arrival between Lituya Bay and Prince William Sound.

ment of *P. sitchensis,* and this interval was presumably drier than succeeding millennia (Mathewes and Heusser, 1981). Thus climate may have played a role in limiting *P. sitchensis* migration during this period. The long 4800-yr interval (7600–2780 yr B.P.) before *P. sitchensis* expanded at Prince William Sound, however, is puzzling. Wetter conditions along the coast would seemingly have been favorable for continued westward migration. Possibly the species simply did not find suitable sites for colonization or perhaps wind conditions were not favorable for transport to the northwest.

Migration rates of *T. heterophylla* between Lituya Bay and Yakutat (7140–6170 yr B.P.) and between Yakutat and Icy Cape (6170–3860 yr B.P.) are very similar to those of *P. sitchensis*. However, *T. heterophylla* reached Prince William Sound from Icy Cape in approximately 1200 yr (3860–2680 yr B.P.), a much shorter time than did *P. sitchensis*. One explanation for its rapid movement northwestward in the last 3800 yr is the increase in climatic and edaphic moisture which accompanied Neoglaciation and which *T. heterophylla* favors.

The phytogeographical history of the Malaspina Glacier district, reflecting conifer migration along a coastal strip of land, is dependent upon rates of seed dispersal. Seeds of both *P. sitchensis* and *T. heterophylla* are similar in weight and wing length

(USDA, 1948); thus, dissemination distance is likely comparable. In contrast, *T. mertensiana* seeds are twice as heavy, and this may have influenced the geographic expansion of this characteristic montane–subalpine species. Recorded at Lituya Bay at 4860 yr B.P., *T. mertensiana* took approximately 2000 yr (4860–3000 yr B.P.) to reach the Yakutat region, where it is poorly represented. However, if *T. mertensiana* reached Icy Cape earlier (3500 yr B.P.), it may have colonized montane–subalpine sites to the northwest and southeast when Neoglacial conditions prevailed. Its expansion in Prince William Sound close to 2680 yr B.P. parallels alpine glacier expansion throughout the Northern Hemisphere during approximately 3300–2400 yr B.P. (Denton and Karlén, 1973).

CONCLUSIONS

(1) Palynology, macrofossil analysis, and radiocarbon chronology of muskegs within the Malaspina Glacier district permit distinctions to be made between sequences of plant succession, postglacial conifer migration, and climatic change throughout the last 10,000 yr.

(2) Seventy surface pollen samples from *P. sitchensis, T. heterophylla,* coastal meadow, muskeg, tree line, and alpine tundra communities, generally characterize the vegetation by their pollen signatures and provide a basis for interpreting fossil pollen assemblages.

(3) A modern analog for Gramineae–Cyperaceae–*Artemisia* fossil pollen assemblages is found in modern alpine tundra. *Alnus*–Polypodiaceae fossil pollen and spore assemblages, representing pioneer vegetation throughout the district, sometimes mask a more diverse species composition including *Rubus spectabilis* and *Sambucus racemosa,* as evidenced by seeds.

(4) Climatic amelioration approximately 10,000 yr ago led to an early Holocene xerothermic interval (10,000 to 7600 yr B.P.) in which *Alnus* was dominant. *P. sitchensis* arrived at Icy Cape approximately 7600 yr B.P., as needles, seeds, sterigmata, and pollen imply. Wetter conditions ensued in the subsequent millennia, enabling generative muskeg surfaces to develop. *T. heterophylla* was able to expand, and reached Yakutat close to 6100 yr B.P.; Icy Cape records its presence about 3900 yr B.P. Climatic cooling and increasing atmospheric moisture approximately 3500 yr B.P. is implied by the appearance of *T. mertensiana* and *S. selaginoides* in the fossil record.

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